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UNITED STATES PATENT APPLICATION  
FOR

COMPENSATION OF LATERAL POSITION CHANGES IN PRINTING

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## FIELD OF THE INVENTION

The present invention relates to compensation of lateral position changes in printing and, for example, to a method of compensating lateral position changes of a moving recording medium during a print process and to a printing device.

## BACKGROUND OF THE INVENTION

Multicolor printers generate images which are composed of a plurality of different single-color images. The quality of the final multicolor image depends on the accuracy of the alignment of the individual images (also called "registration accuracy"). With the increasing resolution of modern printers the registration accuracy has become an issue of interest.

Different printing techniques are known. For example, in ink-jet printing droplets of liquid ink are directed from print heads towards a recording medium. Each print head has a plurality of ink channels. Pulses cause droplets of ink to be expelled as required from dot-forming elements in the form of orifices or nozzles at the end of the channels. These pulses are generated e.g. by thermal components in thermal ink-jet print heads or by piezo-electric elements in drop-on-demand print heads. Page-wide array ink-jet printers have an array of nozzles extending across the full width of the recording medium. The recording medium may be paper or any other suitable substrate to which the ink adheres, and is moved past the print heads by a conveyor formed, for example, by a belt or a drum.

The print heads are arranged in print stations which are typically transversely oriented to the conveyor's advance direction and are spaced apart from each other in the advance direction. Due to the spaced arrangement of the print stations, the individual images are subsequently printed. If the distance between the print stations is smaller than the image length the individual images are printed in a staggered manner. Accordingly, the multicolor image to be printed is virtually separated into individual images to be printed by the respective print stations. In order to achieve registration of the images

1 with respect to the advance direction (or longitudinal direction), the printing  
2 activity of the individual print stations is delayed until the image printed by the  
3 first print station arrives at the respective subsequent print station.

4 Assuming that the conveyor only moves the recording medium in the  
5 longitudinal direction, registration can be achieved by choosing the correct  
6 delays. However, small movements in a direction perpendicular to that may  
7 cause a lateral displacement of the recording medium from one print station  
8 to the other and, accordingly, a lateral misalignment of the individual images.  
9 Such lateral displacements may, for example, occur when the conveyor belt  
10 runs askew or performs oscillatory lateral movements.

11 In order to also achieve registration with respect to such lateral  
12 displacements, it is known to shift the image data to be printed by the  
13 individual print stations to compensate for this lateral displacement (see, for  
14 example, US patents No. 5,587,771 and 6,335,748).

15 A printing device with a conveyor in the form of a rotating drum is known  
16 from US patent No. 6,089,693. The printing device has a single print station.  
17 Due to large numbers of dot-forming elements (nozzles) in the print station,  
18 generally one or more of the nozzles will be defective. During a first pass (i.e.  
19 a first revolution of the drum), the print station prints the complete image, ex-  
20 cept for one or more columns corresponding to the defective nozzle or noz-  
21 zles. Then the print station is laterally shifted, so that an operative nozzle is  
22 aligned to the original position of the defective nozzle. During a second pass  
23 (i.e. a second revolution of the drum) the missing column(s) is (are) printed.

## 24 25 SUMMARY OF THE INVENTION 26

27 A first aspect of the invention is directed to a printing device. According  
28 to the first aspect, the printing device comprises: a plurality of print stations  
29 including dot-forming elements arranged to produce an image on a moving  
30 recording medium and provided in a redundant manner, thereby enabling dot-  
31 forming-element activity to be distributed between redundant dot-forming  
32 elements and errors of dot-forming elements to be compensated; a lateral-  
33 position detector arrangement or predictor arranged to indicate the recording

1 medium's lateral position relative to the print stations during a print process;  
2 and a controller arranged to use at least one print mask for each print station  
3 arranged to distribute the dot-forming-element activity and to compensate the  
4 errors of dot-forming elements. The printing device is arranged so that, in re-  
5 sponse to a detected or predicted change of the relative lateral position, at  
6 least one of the currently used print masks is replaced by another one relating  
7 to the changed relative lateral position.

8 According to another aspect a printing device is provided, comprising: a  
9 plurality of print stations including dot-forming elements arranged to produce  
10 an image on a moving recording medium and provided in a redundant man-  
11 ner, thereby enabling dot-forming-element activity to be distributed between  
12 redundant dot-forming elements and errors of dot-forming elements to be  
13 compensated; a lateral-position detector arrangement or predictor arranged to  
14 indicate the recording medium's lateral position relative to the print stations  
15 during a print process; a controller arranged to use at least one print mask for  
16 each print station arranged to distribute the dot-forming-element activity and  
17 to compensate the errors of dot-forming elements; and a print-mask memory  
18 arranged to store print masks for different lateral recording medium's posi-  
19 tions. The controller is arranged, in response to a detected or predicted  
20 change of the lateral position, to use at least one other print mask from the  
21 stored print masks than the currently used one, this at least one other print  
22 mask relating to the changed lateral position.

23 According to another aspect a printing device is provided, comprising: at  
24 least one print station including dot-forming elements arranged to produce an  
25 image on a moving recording medium; a drum arranged to convey the re-  
26 cording medium past the at least one print station, wherein, by performing  
27 more than one turn, the drum is enabled to convey the recording medium  
28 more than once past the at least one print station, thereby creating an effec-  
29 tive dot-forming-element redundancy; a lateral-shift mechanism arranged to  
30 perform a relative lateral shift between the print station and the recording me-  
31 dium from one drum turn to another drum turn, thereby enabling dot-forming-  
32 element activity to be distributed between drum turns and errors of dot-  
33 forming elements to be compensated; a lateral-position detector arrangement

1 or predictor arranged to indicate the relative lateral shift between the re-  
2 cording medium and the print station; and a controller arranged to use at least  
3 one print mask for the at least one print station for each drum turn and each  
4 detected or predicted relative lateral position between the print station and the  
5 recording medium. The print masks are arranged to distribute the dot-forming-  
6 element activity between the drum turns and, in addition, to compensate the  
7 errors of dot-forming elements.

8 According to another aspect a printing device is provided, comprising: at  
9 least one print station including dot-forming elements arranged to produce an  
10 image on a moving recording medium; a drum arranged to convey the re-  
11 cording medium past the at least one print station, wherein, by performing  
12 more than one turn, the drum is enabled to convey the recording medium  
13 more than once past the at least one print station, thereby creating an effec-  
14 tive dot-forming-element redundancy; a lateral-shift mechanism arranged to  
15 perform a relative lateral shift between the print station and the recording me-  
16 dium from one drum turn to another drum turn, thereby enabling dot-forming-  
17 element activity to be distributed between drum turns and errors of dot-  
18 forming elements to be compensated; a lateral-position detector arrangement  
19 or predictor arranged to indicate the recording medium's lateral position rela-  
20 tive to the print station; a print-mask memory arranged to store print masks for  
21 each drum turn and each detected or predicted relative lateral position be-  
22 tween the print station and the recording medium, wherein the print masks  
23 are arranged to distribute the dot-forming-element activity between the drum  
24 turns and in addition to compensate the errors of dot-forming elements; and a  
25 controller arranged to use at least one print mask from the stored print masks  
26 for the at least one print station during the printing operation.

27 According to another aspect a method is provided of compensating lat-  
28 eral position changes of a moving recording medium during a print process, in  
29 which at least one image is printed by a plurality of print stations including  
30 dot-forming elements, based on image data. Redundant dot-forming elements  
31 are provided, thereby enabling dot-forming-element activity to be distributed  
32 between redundant dot-forming elements, and errors of dot-forming elements  
33 to be compensated, by using print masks. The method comprises: detecting

1 or predicting the lateral position of the recording medium relative to the print  
2 stations during a print process; using the image data and at least one print  
3 mask for each print station to distribute the dot-forming-element activity be-  
4 tween the print stations and to compensate the errors of dot-forming ele-  
5 ments; and replacing, in response to a detected or predicted change of the  
6 lateral position, at least one of the currently used print masks by another one  
7 relating to the changed relative lateral position.

8       According to another aspect a method is provided of compensating lat-  
9 eral position changes of a moving recording medium during a print process, in  
10 which at least one image is printed by a plurality of print stations including  
11 dot-forming elements, based on image data. Redundant dot-forming elements  
12 are provided, thereby enabling dot-forming-element activity to be distributed  
13 between redundant dot-forming elements, and errors of dot-forming elements  
14 to be compensated, by using print masks, wherein a set of such print masks  
15 for different relative lateral positions of the recording medium is pre-calculated  
16 and stored. The method comprises: detecting or predicting the lateral position  
17 of the recording medium relative to the print stations during a print process;  
18 using the image data and at least one print mask for each print station to dis-  
19 tribute the dot-forming-element activity between the print stations and to com-  
20 pensate the errors of dot-forming elements; and using, in response to a de-  
21 tected or predicted change of the relative lateral position, at least one other  
22 print mask from the stored print masks than the currently used one, this at  
23 least one other print mask relating to the changed relative lateral position.

24       According to another aspect a method is provided of compensating lat-  
25 eral relative position changes of a moving recording medium during a print  
26 process, in which at least one image is printed, based on image data, by at  
27 least one print station of a drum system during more than one drum turn. Ef-  
28 fective dot-forming-element redundancy is created by executing additional  
29 drum turns and laterally shifting the print station between drum turns, thereby  
30 enabling dot-forming-element activity to be distributed between the drum  
31 turns and errors of dot-forming elements to be compensated, by using print  
32 masks. The method comprises: detecting or predicting the lateral position of  
33 the recording medium relative to the at least one print station during a print

process; using the image data and at least one print mask for each print station for each drum turn and detected or predicted relative lateral position between the print station and the recording medium, wherein the print masks distribute dot-forming-element activity between the drum turns and, in addition, compensate the errors of dot-forming elements.

According to another aspect a method is provided of compensating lateral relative position changes of a moving recording medium during a print process, in which at least one image is printed, based on image data, by at least one print station of a drum system during more than one drum turn. Effective dot-forming-element redundancy is created by executing additional drum turns and laterally shifting the print station between drum turns, thereby enabling dot-forming-element activity to be distributed between the drum turns and errors of dot-forming elements to be compensated, by using print masks. A set of such print masks for different relative lateral positions of the recording medium is pre-calculated and stored. The method comprises: detecting or predicting the lateral position of the recording medium relative to the at least one print station during a print process; and using the image data and at least one print mask from the stored print masks for each print station for each drum turn and detected or predicted relative lateral position between the print station and the recording medium, wherein the print masks distribute dot-forming-element activity between the drum turns and, in addition, compensate the errors of dot-forming elements.

Other features are inherent in the methods and products disclosed or will become apparent to those skilled in the art from the following detailed description of embodiments and its accompanying drawings.

## DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of example, and with reference to the accompanying drawings, in which:

Fig. 1 illustrates an embodiment of a printing device having a belt conveyor;

Fig. 2 illustrates an embodiment of a lateral-position detector ar-

1 rangement with longitudinally extending encoding marks;

2 Fig. 3 illustrates another embodiment of a lateral-position detector  
3 arrangement with angled encoding marks;

4 Fig. 4 illustrates print control of two redundant print stations for six  
5 different cases (a-f), including cases with a lateral recording medium shift and  
6 different attempts to compensate it (b-f);

7 Fig. 5 is a flow diagram illustrating pre-calculation of print masks  
8 and their use during printing in order to compensate lateral position changes;

9 Fig 6 illustrates another embodiment of a printing device having a  
10 drum conveyor.

## 11 DESCRIPTION OF THE PREFERRED EMBODIMENTS

12  
13  
14 Fig. 1 illustrates an embodiment of a printing device. Before proceeding  
15 further with the detailed description of Fig. 1, however, a few items of the em-  
16 bodiments will be discussed.

17 In some of the embodiments, the printing device is equipped with a plu-  
18 rality of print stations which are successively passed by the recording medium  
19 conveyed by a conveyor (e.g., a belt) during a print process. The print stations  
20 are arranged to print single-color images. In embodiments enabling multicolor  
21 images to be printed, each print station prints a part of the entire multicolor  
22 image. The printing is based on input image data virtually separated into data  
23 representing the individual image parts printed by the respective print sta-  
24 tions. A multicolor image is typically separated into four single-color images  
25 (the separation is, for example, based on the basic colors cyan, magenta,  
26 yellow and black). As will be explained below, the print stations have dot-  
27 forming elements (e.g. nozzles) which, in some of the embodiments, are ar-  
28 ranged in a redundant manner for each individual color. In some of these em-  
29 bodiments, the redundancy is achieved by doubling the print stations for each  
30 color; i.e. these embodiments have two cyan, magenta, yellow and black print  
31 stations. In other embodiments, each single-color print station has a redun-  
32 dant arrangement of dot-forming elements, e.g. four print stations with two  
33 page-wide arrays of dot-forming elements. Redundant print stations (or re-



dundant arrangements of dot-forming elements) form what is called a "redundancy group"; for example, two redundant print stations of the same color form a redundancy group.

In other embodiments, redundancy is not achieved by doubling (or multiplying) the number of print stations of the different colors, but rather by doubling (or multiplying) the number of times the recording medium is moved past a print station (i.e. the number of passes), and by laterally shifting the print station relative to the recording medium between two subsequent passes. In some of these other embodiments, the conveyor is in the form of a rotating drum facing a print station (or several print stations for different colors). The recording medium is attached to the surface of the drum, and the several passes of the recording medium are performed by repeated revolutions of the drum.

The redundancy (either achieved by multiplying the number of print stations or the number of passes) enabling the dot-forming-element activity to be distributed between the redundant dot-forming elements or the different passes. For example, the first print head of two redundant print heads prints about one half of the dots or of the picture elements (analogously, during a first pass the first half may be printed, and during a second pass the second half), and the second print head prints the other half. Generally, the print activity may be distributed such that blocks of contiguous dots or picture elements printed by one print station or in one pass are minimized or, at least, reduced, which improves image quality. For example, in the case of a distribution between two print stations or passes, the print activity may be distributed according to a checkerboard-like pattern. Furthermore, the redundancy enables an "error hiding", i.e. defective (or faulty) dot-forming elements to be compensated by operative dot-forming elements, as will be explained in more detail below. In embodiments in which redundancy is achieved by several passes, the print station and the recording medium are laterally shifted relative to each other between passes, in order to enable an operational dot-forming element to take over the function of a faulty one, in the second pass.

Distributing the print activity means, herein, distributing it to a greater extent than would be required to obtain only error hiding. In other words, it

1 means that the print activity is distributed between different print stations or  
2 passes, even in the case in which all dot-forming elements are operational  
3 (i.e. in the case in which no errors are hidden). In contrast, in the US patent  
4 No. 6,089,693 mentioned at the outset, not distributed printing is performed  
5 since everything is printed during the first pass, but only the task of the defec-  
6 tive nozzles is performed by shifted operational nozzles during the second  
7 pass (i.e. nothing is printed in the second pass if all nozzles are operational).

8 In the embodiments, the recording medium is paper or any other suit-  
9 able substrate. It may be subdivided in sheets (e.g. paper sheets). A print  
10 process may extend over one sheet or several sheets.

11 In some of the embodiments, the recording medium is advanced by a belt con-  
12 veyor in the longitudinal direction. While conveyed past the print stations, the re-  
13 cording medium may change its lateral position. The recording medium's dis-  
14 placement in the lateral direction may, for example, be due to a correspond-  
15 ing lateral belt displacement occurring during the mainly longitudinal belt  
16 movement. In embodiments having a drum conveyor, the recording medium  
17 may also move laterally relative to the drum during the drum revolutions. Fur-  
18 thermore, shifting the print station between two drum revolutions also repre-  
19 sents a relative lateral shift between the recording medium and the print sta-  
20 tion. When the mechanism causing the lateral shift of the print station is not  
21 controlled to a precision corresponding to the print resolution, an uncontrolled  
22 relative lateral movement between print station and recording medium will  
23 appear from one drum revolution to the other. In principle, a lateral displace-  
24 ment of the drum might also occur.

25 A lateral displacement between the different print stations, or the differ-  
26 ent revolutions, would, in principle, result in a "misregistration" of the individ-  
27 ual images printed. In order to enable such a lateral displacement to be com-  
28 pensated, the recording medium's relative lateral position is either detected or  
29 predicted for each print station. In some of the embodiments, the detection or  
30 prediction is indirect, in the sense that the belt's or drum's lateral position is  
31 detected or predicted for each print station, and it is assumed that a detected  
32 or predicted lateral position change of the belt or drum causes a correspond-  
33 ing lateral position change of the recording medium. In belt-conveyor em-

1   bodiments with lateral position detection, a lateral-position detector arrange-  
2   ment is provided at each print station. For example, in one embodiment, the  
3   conveyor belt is equipped with encoding marks indicative of the belt's lateral  
4   position (e.g. encoding marks with two angled positions), and the sensor ar-  
5   rangement has sensors responsive to the encoding marks and arranged to  
6   determine the belt's lateral position from the detected encoding marks.

7         In other embodiments (belt or drum embodiments) the encoding marks  
8   may be applied to (e.g. printed on) the recording medium itself, in order to  
9   directly detect the recording medium's relative lateral position.

10        In still other embodiments, in which a recording medium with an irregular  
11   surface structure (such as a paper-fiber structure) is used, the detector ar-  
12   rangement is arranged to directly detect the recording medium's lateral posi-  
13   tion without such pre-applied marking on the recording medium. Images of  
14   the surface structure are taken with the detector arrangement at the first print  
15   station, or during the first drum revolution, as the recording medium ad-  
16   vances, and are stored in a memory. At the second (or subsequent) print sta-  
17   tion, or drum revolution, images of the surface structure are taken with the  
18   detector arrangement and compared with the corresponding stored surface  
19   images taken at the first print station, or drum revolution. A lateral shift of the  
20   second images shifted with respect to the stored first ones can be detected  
21   and used as an indication of a corresponding lateral shift of the recording  
22   medium. However, basing the lateral-shift detection on a comparison of dif-  
23   ferent surface images implies that a lateral shift can only be detected when  
24   the shifted recording medium reaches the second detector, or when the sec-  
25   ond revolution is performed. A suitable surface image recording device is de-  
26   scribed in US patent No. 6,118,132.

27        In still other drum embodiments the lateral-position detector arrange-  
28   ment detects the actual lateral position of the laterally movable print sta-  
29   tion(s).

30        In some embodiments, the lateral conveyor or recording medium posi-  
31   tion depends, in a reproducible manner, on a known parameter of the con-  
32   veyor (which is, for example in a belt embodiment, the case if the belt pro-  
33   duces a reproducible lateral oscillation depending on the longitudinal belt po-

1 sition). This enables the lateral conveyor or recording medium position to be  
2 predicted for each print station or drum revolution by a model calculation, the  
3 input parameter of which is, for example in belt embodiments, the current  
4 longitudinal belt position.

5 Some embodiments use a combination of detection and prediction. For  
6 example, in a belt embodiment, the belt's lateral position is measured at one  
7 or two points along the belt (e.g. before the first and after the last print sta-  
8 tion), and its lateral positions at each print station are then predicted by ex-  
9 trapolation or interpolation, based on this measurement. The either detected  
10 or predicted lateral positions are then input into a controller to compensate for  
11 lateral shifts, as will be explained below.

12 Each print station includes at least one page-wide array of dot-forming  
13 elements. A print station may be subdivided, along the width of the print sta-  
14 tion, in several independent sub-arrays of dot-forming elements, called "print  
15 heads". The print heads can be exchanged independently from one another,  
16 which obviates a need to replace a complete print station in the event of a  
17 fault which affects only a part of the print station. In ink-jet printer embodi-  
18 ments, the dot-forming elements are orifices or nozzles, through which drop-  
19 lets of liquid ink are ejected towards the recording medium. Embodiments  
20 using other printing techniques have analogous dot-forming elements, for ex-  
21 ample, in laser printers the dot-forming elements may be laser diodes di-  
22 rected to a recording medium in the form of a charged photosensitive print  
23 roller arranged to become discharged in illuminated areas. A charged toner is  
24 then only taken up by the discharged areas and transferred to an output pa-  
25 per sheet. To render the following description more illustrative, the specific  
26 term "nozzles" is used hereinafter; it also stands for other dot-forming ele-  
27 ments, such as light-emitting diodes.

28 In high-resolution printers, each print head has a very large number of  
29 nozzles (typically in the order of  $10^3$ - $10^5$ ). Some of a print head's nozzles will  
30 inevitably become faulty in time. For example, in the case of ink jet printers,  
31 faulty nozzles may be nozzles emitting in a false direction, or emitting no ink,  
32 insufficient ink or abundant ink. Owing to the large number of nozzles in a  
33 print head, typically some of them will be faulty, even if the error frequency

1 referring to an individual nozzle is small. It is economically not feasible to re-  
2 place a print head, if only a few nozzles are faulty. However, in order to main-  
3 tain good image quality the function of faulty nozzles is taken over by opera-  
4 tive nozzles. Accordingly, an approach called "error hiding" has been adopted  
5 in the embodiments. It enables nozzle errors to be compensated without  
6 physically replacing any parts of the printing device. In order to achieve this,  
7 in some of the embodiments the nozzles are arranged in a redundant man-  
8 ner. For example, two identical print stations may be provided for each color.  
9 If a nozzle becomes faulty in one of the two print stations, its function can be  
10 taken over by one or more corresponding replacement nozzles of the other  
11 one of the two print stations, thereby hiding (i.e. effectively eliminating) the  
12 error. Shifting the task of a faulty nozzle to a corresponding (originally redun-  
13 dant) one is performed by using print masks, as will be explained below. In  
14 the following example, for sake of simplicity, it will be considered the case in  
15 which each nozzle can be replaced just by one corresponding redundant noz-  
16 zle, which is the normal case when, for instance, the printer is printing at a  
17 printing resolution corresponding to the nozzle resolution. Clearly, when the  
18 printing resolution is lower than the nozzle resolution, more nozzles can print  
19 the same information and then more nozzles can be used for replacing the  
20 error nozzle. The same mechanisms and methods described in the following  
21 can still be applied to printer printing at resolutions allowing one nozzle to be  
22 replaced by a corresponding nozzle chosen out of a plurality of nozzles.

23 In the embodiments, the printing device is equipped with a nozzle-error  
24 detector, for example, in the form of a page-wide optical sensor array. In  
25 some embodiments, test print-outs are produced from time to time and  
26 viewed by the sensor array. The images printed as test print-outs are chosen  
27 such that they enable a missing or otherwise abnormal ink dot to be assigned  
28 to a certain nozzle in a certain print head, thereby enabling faulty nozzles to  
29 be identified. For example, dots from different print heads or rows of nozzles  
30 are not printed in an overlaid manner, but individually in the test print-out to  
31 enable the assignment mentioned above. In other embodiments, the informa-  
32 tion obtained by the optical sensor array by viewing images printed by the  
33 ensemble of print heads during the printer's normal operation is used to iden-

1 tify faulty nozzles. Owing to the fact that, typically, at least in some regions of  
2 the printed multicolor images only a single-color inking is required, comparing  
3 the actually printed images in such regions with the desired printed images  
4 also enables missing or otherwise abnormal ink dots to be detected and as-  
5 signed to certain nozzles in certain print heads. Accordingly, in the latter em-  
6 bodiment faulty nozzles can be identified without test print-outs.

7 In still further embodiments, each print station is equipped with an indi-  
8 vidual nozzle-error detector which is arranged to directly detect faulty nozzles,  
9 e.g. by monitoring ink drop generation, but without "looking" at the print result  
10 on the paper. For example, in some embodiments, the nozzle-error detector  
11 is made up of a plurality of light barriers crossed by the ink drops expelled by  
12 the nozzles. A fault of a nozzle is indicated if the light barrier associated with  
13 a certain nozzle is not interrupted when the nozzle is fired. In other embodi-  
14 ments, a nozzle-error detector is provided which analyzes the noise produced  
15 by the nozzles upon operation; faulty nozzles are identified by missing or ab-  
16 normal noise production. In still further embodiments, a capacitive nozzle-  
17 error detector is used which measure capacitive changes when a nozzle is  
18 fired, and detects faulty nozzles by missing or abnormal capacitive changes.  
19 Data representing information about faulty nozzles is stored and used to pro-  
20 duce error-hiding print masks.

21 Print masks are (preferably two-dimensional, but can also have three or  
22 more dimensions) control tables (or patterns) for controlling the activity of the  
23 individual nozzles for the individual rows of the image to be printed. The print  
24 masks control the distribution of print activity between redundant nozzles or  
25 drum turns, and also control the error hiding. The print masks are independ-  
26 ent of a particular image to be printed, i.e. the particular image information is  
27 carried by the input image data (but they may depend on the image type).  
28 Each print station has its individual print mask or masks. In practice, when a  
29 print stations segmented into print heads, the print mask of a print station may  
30 be correspondingly segmented, so that each print head may have its own  
31 print mask. However, the terminology used herein refers to a "print mask" as  
32 the print mask of an entire print station (which may actually be an assembly of  
33 smaller print masks, each associated with a print head). For example, the

1 print mask of a certain print station defines each nozzle of this print station to  
2 be "enabled" or "disabled", which means that the respective nozzle is enabled  
3 to print or remains inactive. As a simple example, a logical AND is formed  
4 between the input image and the print mask for each image dot; if, for a cer-  
5 tain image in a certain line, the input image requires ink to be applied to the  
6 dot (logical "1") and the print mask enables the corresponding nozzle (logical  
7 "1") in this line, the nozzle is activated (i.e. it applies ink). However, if the input  
8 image defines that no ink is to be applied (logical "0"), and/or the print mask  
9 disables the nozzle (logical "0"), the nozzle is not activated (i.e. no ink is ap-  
10 plied to this dot). In some of the embodiments, more complicated print masks  
11 are used, for example, to achieve half-toning besides print-activity distribution  
12 and error hiding. In these embodiments, more than one nozzle is provided for  
13 each picture element (pixel) of the input image; for example, four nozzles are  
14 provided for each pixel. By activating one, two, three or four of a pixel's noz-  
15 zles, four different color densities can be printed (this technique is also called  
16 "dithering"). The print mask for each pixel may be a threshold matrix which  
17 defines that the respective nozzle is only enabled if the input image's color  
18 density for this pixel is above the respective threshold. Accordingly, in the  
19 embodiments using half-toning, the logical-AND procedure described above  
20 may be replaced by a thresholding procedure. In some embodiments, sepa-  
21 rate print masks for print-activity distribution with error hiding and halftoning  
22 are used for every print station. The nozzle activity of a print station may then  
23 be controlled by a logical combination of the separate print masks.

24 As already mentioned above, in the embodiments, the nozzles are pro-  
25 vided in a redundant manner, or redundancy is achieved by multiple drum  
26 turns to enable the print activity to be distributed and nozzle errors to be hid-  
27 den. For example, in some embodiments, the redundancy is achieved by  
28 doubling the number of single-color print stations, e.g. by providing two cyan,  
29 magenta, yellow and black print stations, which are eight print stations in total.  
30 In the embodiments, the print masks define how a printing task is distributed  
31 between the redundant nozzles, i.e. which one of two redundant nozzles is  
32 activated to apply ink to a particular dot, and which one is not activated. For  
33 example, in the ideal case of print stations without any nozzle errors, the print

1 masks of two redundant print stations of one color which form a redundancy  
2 group (which may also be represented by one and the same print station in  
3 two different drum turns) may be arranged like complementary checkerboard  
4 patterns. Such complementary checkerboard patterns equally distribute the  
5 print task to the two print stations of a redundancy group and add up to a  
6 complete coverage. More generally, the print masks of redundant print sta-  
7 tions associated with each may be complementary patterns minimizing or re-  
8 ducing blocks of contiguous dots or picture elements printed by each print  
9 station, or during each drum turn. Distributing the print activity typically im-  
10 proves the image quality achieved since, for example in ink jet printing, it en-  
11 ables the ink applied by the first print station, or during the first drum turn, to  
12 dry until the print process is continued, thereby enabling more ink to be ap-  
13 plied, which may improve the color intensity. Furthermore, combining error  
14 hiding with distributed printing provides better quality than printing only miss-  
15 ing columns of defective nozzles in a second pass, since such columns may  
16 be visible in the final printed image. Although a symmetric distribution  
17 (50%:50% between two redundant print stations) is advantageous, in some  
18 embodiments an asymmetric distribution of the print activity is chosen, for  
19 example 70% of the print activity by the first print station, or in the first drum  
20 turn, and only 30% by the second print station, or in the second turn, in par-  
21 ticular in embodiments in which not all faulty nozzles of the second print sta-  
22 tion, or the second turn, are hidden by the print activity of the first print station,  
23 or in the first turn, as will be explained below.

24       If faulty nozzles are present, the print masks which distribute the print  
25 activity between the nozzles of a redundancy group, or between drum turns,  
26 in a normally regular manner, are modified so as to hide the nozzle errors.  
27 For example, assuming that one nozzle in one of the print stations of a re-  
28 dundancy group has become faulty. Then, in the print mask associated with  
29 this print station, all fields in the print-mask row corresponding to the position  
30 of the faulty nozzle are set to "0". Thereby, for example, the regular checker-  
31 board pattern mentioned above is disturbed. In the print mask of the other  
32 print station of the redundancy group, all fields of the corresponding print-  
33 mask row are set to "1", so that the two masks are complementary. Accord-



1 ingly, the faulty nozzle is disabled, and its print task is taken over by the cor-  
2 responding other nozzle of the redundancy group. The nozzle error will not  
3 appear in the print-out. In the embodiments, the printing device is arranged,  
4 upon identification of new nozzle errors, to calculate new print masks taking  
5 into account such newly discovered nozzle errors and to replace the currently  
6 used print masks by these updated ones.

7       As explained above, in the embodiments, lateral shifts of the recording  
8 medium detected at a certain print station are compensated by data shift op-  
9 erations, so as to maintain the registration of the individual images printed  
10 onto each other. However, as can be seen from the example above, the print-  
11 ing activity of the print stations belonging to a redundancy group, or during  
12 different passes, are correlated; accordingly, if one requires the print masks  
13 associated with redundant print stations to be complementary and provide full  
14 coverage, when combined, at least the print masks of the print stations form-  
15 ing a redundancy group are correlated.. Due to the print masks' correlation, it  
16 is generally not sufficient only to shift the input image in order to compensate  
17 for a lateral recording medium displacement at a particular print station. This  
18 is because shifting only the image data without shifting the print mask of the  
19 respective print station would result in an image in which some dots are erro-  
20 neously left blank, and on other dots ink would be applied twice. On the other  
21 hand, if the print mask associated with the respective print station were  
22 shifted together with the image, it would no longer be complementary to the  
23 print mask of the other print station of the redundancy group. This, in turn,  
24 would cause some dots to be left blank or inked twice. Therefore, if a lateral  
25 displacement is detected at a certain print station, the current print mask as-  
26 sociated with this print station is replaced by another print mask relating to the  
27 changed lateral position. This new print mask, in principle, is a shifted print  
28 mask, in which the amount of shift corresponds to the detected lateral shift of  
29 the recording medium. However, those parts of the print mask which corre-  
30 spond to faulty nozzles of the respective print station are not shifted together  
31 with the whole print mask. Rather, in the new print mask these parts are lo-  
32 cated at a different position within the mask, so as to take into account that,  
33 although the mask has been shifted, that the faulty nozzles have not been

1 shifted. Owing to the correlation of the print masks of the print stations of a  
2 redundancy group, the print mask of the other print stations of the redun-  
3 dancy group are also replaced by new complementary print masks, i.e. print  
4 masks which take into account that the position of the faulty nozzles have  
5 effectively been changed in the print mask of the print station at which the  
6 lateral shift has been detected. In other words, the print masks of all print sta-  
7 tions of a redundancy group, between which a relative lateral shift of the re-  
8 cording medium has been detected are replaced by new print masks taking  
9 into account this lateral shift.

10 With regard to error hiding, the correlation between two print stations  
11 forming a redundancy group requires the first print station (or the print station  
12 during the first pass) to take over the printing activity of the second print sta-  
13 tion (or the laterally shifted position of the print station during the second  
14 pass) for those columns in which a second print station (or the print station at  
15 the laterally shifted position) has faulty nozzles. *Vice versa*, the second print  
16 station (or the print station during the second pass) has to take over the print  
17 activity of the first print station (or the print station during the first pass) for  
18 those columns in which the first print station has faulty nozzles. In principle,  
19 this requires not only the print mask of the second print station of a redun-  
20 dancy group (or the second pass), but also the print mask of the first print sta-  
21 tion (or the first pass) to be replaced by print masks relating to the new rela-  
22 tive lateral position, in order to make the two print masks fully complementary  
23 and achieve complete error hiding. However, there are a couple of cases in  
24 which the first print station has already printed its partial image, or a part of it.  
25 What has already been printed, cannot be changed any more. In particular,  
26 for that part which the first print station already printed, it will not be able to  
27 take over the printing activity of the second print station's faulty nozzles, since  
28 these nozzles will now, after the occurrence of the relative lateral shift, be ef-  
29 fectively positioned at different lateral positions from the ones assumed by the  
30 first print station before the lateral shift occurred. Only the second print station  
31 is able to still take into account the relative lateral shift and take over the print  
32 task of the first print station's faulty nozzles. Therefore, using a new print  
33 mask relating to the new relative lateral position at the second print station (or

the second pass) enables a partial error hiding, but a perfect error hiding will generally not be achievable in such cases of a "delayed" detection of a relative lateral replacement. For example, when a belt of a belt conveyor changes its skew angle resulting in a relative lateral displacement at the second print station, that part of the image which has already been printed by the first print station, but has not yet been printed by the second print station, will not be affected any more by the new print mask for the first print station relating the new relative lateral position, but will only be affected by the new print mask for the second print station. Therefore, for a "transitional phase" (which lasts until the print-out of first print station printed with the new print mask reaches the second print station), no complete error hiding will be achieved. Complete error hiding will be achieved for that part of the image printed by the first print station after the first print station's print mask has been replaced by another print mask relating to the changed relative lateral position.

In printing devices in which redundancy is achieved by multiplying the number of print stations, the length of this transitional region corresponds to the distance between the first and last print station of a redundancy group, and may thus be minimized by arranging the print stations belonging to a redundancy group as close as possible in the advance direction.

In embodiments in which the redundancy is achieved by multiplying the number of passes, the transitional region tends to be longer. For example, if the paper on the drum of a drum conveyor is laterally displaced in the middle of the first drum revolution, the already printed first half of the image printed during the first revolution is a "transitional region". In the case in which the relative lateral displacement between print station and recording medium happens when the print station is laterally shifted between the first and second revolution (which may be the case when this lateral shift of the print head is not controlled to the required precision), then the entire image is the "transitional region" in which only partial error hiding will be achieved.

Incidentally, in some of the embodiments the print masks are only replaced if a different relative lateral shift is detected between two print stations of a redundancy group (i.e. if the belt of a belt conveyor changes its skew angle). However, if the same lateral shift is detected for two such print stations,

1 only the image data are shifted, but the old print masks continue to be used.  
2 In other embodiments, the print masks are even replaced in the latter case  
3 (i.e. in the case in which both print stations of the same redundancy group  
4 detect the same lateral shift). For example, if additional half-toning masks are  
5 used and combined with described error-hiding masks, as mentioned above,  
6 lateral sub-pixel shifts may be compensated by replacing the combined  
7 masks of all print stations subjected to the lateral shift by new print masks  
8 relating to the lateral position changed in common.

9 In some of the embodiments in which the redundancy is achieved by  
10 multiplying the number of print stations of the same color, the replacement of  
11 print masks upon detection of a lateral recording medium displacement is per-  
12 formed from page to page. If a lateral displacement occurs during the printing  
13 of a particular page, the print masks will only be replaced by new print masks  
14 relating to the changed lateral position at the start of the next page. Since one  
15 print process may include more than one page to be printed, the print mask  
16 replacement may take place within a print process. In some of the embodi-  
17 ments in which the redundancy is achieved by multiplying the number of  
18 passes, the replacement of print masks upon detection of a lateral recording  
19 medium displacement is performed for the next pass; i.e. the current print  
20 mask will only be replaced by new print mask relating to the changed lateral  
21 position at the start of the next pass. In other embodiments, the print mask  
22 replacement is performed within the currently printed page or pass upon de-  
23 tection of a lateral displacement. For example, a page to be printed is subdi-  
24 vided into several transversely extending blocks (e.g. four blocks). If a lateral  
25 position change occurs within one of those blocks, the currently used print  
26 masks are replaced by new ones relating to the changed lateral position at  
27 the start of the next block.

28 In some of the embodiments, the new print masks relating to a detected  
29 changed lateral position are calculated in real time ("on the fly") during the  
30 print process. In these embodiments, the newly calculated print masks re-  
31 place the previous ones. For example, the previous print masks may be  
32 dropped, e.g. overwritten by the newly calculated ones.

33 However, in high-resolution printers with a large number of nozzles, cal-

1 calculating a new print mask relating to a changed lateral position may be time-  
2 consuming, even if a high-performance processor is used. In order to enable  
3 a fast compensation upon detection of a lateral shift, other embodiments are  
4 equipped with a print-mask memory arranged to store print masks for different  
5 lateral recording medium positions. Such sets of print masks for different lat-  
6 eral positions are, for example, pre-calculated upon detection of new nozzle  
7 errors, and stored in the print-mask memory. If, during a print process, a lat-  
8 eral position change is detected, the controller reads in and uses those print  
9 masks from the stored set of print masks which relate to the changed lateral  
10 position. Reading pre-calculated print masks from memory can be performed  
11 much faster than calculating new print masks. Therefore, the latter embodi-  
12 ments enable a nearly instantaneous compensation of lateral position  
13 changes in high-resolution printers.

14 In embodiments in which the print masks are only replaced if a different  
15 lateral displacement for the two print stations of a redundancy group has  
16 been detected, it is sufficient to pre-calculate and store only a set of print  
17 masks relating to the possible differences of lateral displacements. This is a  
18 relatively small number of print masks to be pre-calculated and stored. For  
19 example, if then a lateral displacement of two pixels is detected at the first  
20 print station, and a displacement of three pixels at the second print station,  
21 the common displacement by two pixels is taken into account by shifting only  
22 the image data by said two pixels. The remaining 1-pixel difference-  
23 displacement is taken into account by using the pre-calculated print mask for  
24 a 1-pixel difference-displacement compensation, explained in detail in con-  
25 nection with Fig. 4f below. For example, if the embodiment is a 1200 dpi reso-  
26 lution printer, the distance between dots of two adjacent nozzles is about  
27 0.0008 inch, one print mask is necessary to compensate every 0.0008 inch  
28 lateral-difference-position change. Assuming that the maximum lateral-  
29 difference-position change of the embodiments is +/-0.004 inch, about 11 dif-  
30 ferent sets of print masks are pre-calculated and stored. In other embodi-  
31 ments in which all lateral displacements (including equal displacements at the  
32 two print stations of a redundancy group) require a print mask replacement for  
33 the particular absolute displacement, print masks relating to all possible abso-

1 lute displacements are pre-calculated and stored. Due to the number of pos-  
2 sible combinations and such absolute displacements, the number of print  
3 masks to be pre-calculated and stored is relatively large.

4 As can be taken from the explanations above, redundancy may not only  
5 be achieved by multiplying the number of (physical) print stations of each  
6 color, but also by multiplying the number of passes, for example by perform-  
7 ing two or more revolutions of the print medium in a drum system (although,  
8 of course, also in a drum system redundancy may be achieved by providing  
9 more than one physical print station of each color). The explanations made  
10 herein, in particular with regard to print activity distribution and error hiding by  
11 print masks and their replacement methods, also apply to such multi-pass  
12 systems in an analogous manner. However, in order to enable error hiding, a  
13 relative lateral shift between the print station or stations and the recording  
14 medium is actively performed between the passes. For example, if nozzle No.  
15 10 is defective (assuming that the nozzles are numbered from left to right)  
16 and the print station is shifted by four pixels to the left before between the first  
17 and second drum revolutions, the task of the defective nozzle is taken over by  
18 nozzle No. 6 during the second revolution. The "redundancy group" then is  
19 formed by the one print station under consideration, including its print activity  
20 during the two or more passes. Different print masks are associated with the  
21 different passes forming the redundancy group. In a single-color printing de-  
22 vice, there may be only one print station (and one redundancy group); in  
23 multi-color systems there may be several print stations of different colors, e.g.  
24 four print stations (i.e. four redundancy groups).

25 Although the relative lateral shift of the print station(s) between the  
26 passes is actively carried out in order to enable error hiding, it is nevertheless  
27 considered as a lateral displacement of the sort described above, which is  
28 taken into account by replacing a currently used print mask by another one  
29 relating to the new relative lateral position. In particular, in embodiments in  
30 which the active print-station displacement is not mechanically controlled to  
31 the print precision, the actual amount of performed lateral print-station shifting  
32 is detected by a lateral-position detector and handled in manner analogous to  
33 unwanted lateral belt displacements in a belt conveyor.

Returning now to Fig. 1, it shows a printing device 1 in which a recording medium 2 is conveyed in an advance direction 3 by a conveyor belt 4. The recording medium 2 is attached to belt 4, for example, by means of an hold-down vacuum system arranged below the surface of the belt 4. Page-wide-array print stations 5 are arranged along the conveyor belt 4 to produce an image from print data provided by a controller 6. In order to keep Fig. 1 simple, it shows only four print stations 5 for two colors, namely print stations C1 and C2 for "cyan", as well as print stations M1 and M2 for "magenta". The print stations of the same color (C1/C2 and M1/M2) are redundant, and the corresponding pairs each form a redundancy group. Typically, a printer has four colors with eight print stations, forming four redundancy groups. The controller 6 includes a print-mask calculator 7, a print-mask memory 8, and a print-data generator 9. A page-width nozzle-error detector 10 views printed images and forwards data representing the printed images to the controller 6. Each print station 5 is equipped with an encoding-mark sensor 11 responsive to encoding marks 12 arranged at a longitudinal edge of the conveyor belt 4. The encoding marks 12 are indicative of the belt's lateral position. Sensor signals representative of the lateral position are input into the controller 6.

The print-mask calculator 7 calculates new sets of print masks upon detection of new nozzle errors, based on data provided by the nozzle-error detector 10, and stores an updated version of the print-mask set in the print-mask memory 8. The print-data generator 9 receives image input-data 13 from the outside and transforms them to print data sent to the print stations 5 to control nozzle activity during the print process. To this end, it uses the lateral-position information provided by the encoding-mark sensors 11 to select those print masks from the print-mask memory 8 which relate to the current lateral positions, and combines the image input-data 13 with these print masks to generate the print data. If a lateral position change is detected, the currently used print masks are replaced by other print masks from the print-mask memory 8 which relate to the changed lateral position.

Fig. 2a illustrates an embodiment of a lateral-position detector arrangement with a sensor 11 arranged to detect line-like encoding marks 12 which extend in the longitudinal (or advance) direction 3. The sensor 11 extends in

1 the lateral direction. It is responsive to lateral shifts of the encoding marks 12.

2 In Fig. 2b an exemplary lateral shift is illustrated and denoted by "14".

3 Fig. 3a illustrates another embodiment of a lateral-position detector ar-  
4 rangement based on encoding marks 12 which are formed by two lines, one  
5 of which extends in the lateral direction, and the other one in an angle (for  
6 example of 45°) with respect to the first line. The sensor 11 has two sensor  
7 elements responsive to the two lines. The delay between the two signals as-  
8 sociated with such an angled encoder mark 12 represents the lateral position  
9 of the conveyor belt, since a lateral position change illustrated in Fig. 3b (de-  
10 noted by "14") will result in a correspondingly changed delay between these  
11 two signals.

12 Fig. 4 illustrates an example of how an input image 20 is printed by two  
13 print stations 5, 5', which form a redundancy group, by using print masks 21,  
14 21'. The input image 20 is represented by image input-data 13 (Fig. 1). The  
15 print mask 21 is associated with the first print station 5, and the print mask 21'  
16 is associated with the second print station 5' of the redundancy group. Fig. 4  
17 also illustrates an area 22 inked by the first print station 5, as well as an area  
18 22' inked by the second print station 5'. It also illustrates the finally printed  
19 image 23 which is a combination of the inked areas 22 and 22'. The controller  
20 6 (Fig. 1) performs a logical AND of the input image 20 and the print mask 21,  
21 or 21', of the respective print station 5, or 5'. The logical value "1" is illustrated  
22 by black or gray squares in Fig. 4, and the logical value "0" is illustrated by  
23 white squares. The print masks 21, 21' have a generally checkered pattern  
24 and are normally complementary so that a combination of both print marks  
25 21, 21' would lead to a completely gray area (i.e. an area having only logical  
26 values "1").

27 In Fig. 4, it is assumed that one nozzle of the second print station 5' is  
28 faulty; the position of the faulty nozzle is illustrated by a white field in the print  
29 station 5'. The generally checkerboard-like patterns of the print masks 21, 21'  
30 are "disturbed" so as to hide the faulty nozzle of the first print station 5'.

31 Fig. 4a illustrates the case in which no lateral displacement of the belt 4  
32 (Fig. 1) has occurred. The row of print mask 21' that corresponds to the faulty  
33 nozzle in the print station 5' (the fifth nozzle seen from the top in Fig. 4) is



1 completely set to "0", rendering the faulty nozzle of the second print station 5'  
2 inactive. Correspondingly, the same row of the first print station's comple-  
3 mentary print mask 21 is completely set to "1", which means that the corre-  
4 sponding nozzle of the first print station 5 takes over the function of the faulty  
5 nozzle. Both print masks 21, 21' are complementary and, when combined,  
6 cover the entire print area. As illustrated in Fig. 4a, the area 22 inked by the  
7 first print station 5 is a checkerboard-like part of the input image 20, wherein  
8 the fifth row is completely printed. The area 22' inked by the second print sta-  
9 tion 5' is the complementary checkerboard-like pattern within the input image  
10 20, wherein said row (which has been completely printed by the first print sta-  
11 tion 5) is left blank. The combination of the inked areas 22, 22' is the actually  
12 printed image 23. As can be seen in Fig. 4a, the printed image 23 equals the  
13 input image 20. Consequently, the nozzle error of the first print station 5 is  
14 perfectly hidden.

15 Figs. 4b to 4f illustrate cases in which the print medium is laterally  
16 shifted between the first print station 5 and the second print station 5'. In the  
17 example of Fig. 4, the print medium is shifted by one pixel to the top of Fig. 4,  
18 which is illustrated by two relatively shifted plots of the inked area 22, one of  
19 which being provided with a wavy arrow indicating the lateral shift of the print-  
20 medium.

21 Fig. 4b illustrates what will happen if no activity is taken to compensate  
22 the lateral displacement of the print medium, i.e. if neither the image data are  
23 shifted nor the print masks are shifted or changed. Since the assumed lateral  
24 displacement only occurs after the first print station 5, the inked area 22 pro-  
25 duced by the first print station 5 is the same as the one in Fig. 4a. However,  
26 due to the displacement of the print medium by one pixel (in the upward direc-  
27 tion in Fig. 4), the second print station's print mask 21' is effectively (i.e. relat-  
28 ing to the occurred lateral shift of the print medium) no longer complementary  
29 to the first print station's print mask 21. The inked area 22' is produced by the  
30 second print station 5' with an effective displacement of one pixel downwards  
31 relative to the already inked area 22. As a consequence of the fact that the  
32 two, mainly checkerboard-like, print masks 21, 21' are effectively not com-  
33plementary, many of the pixels of the printed image 23 are inked twice, and

1 many others are left blank, resulting in an image of relatively poor image qual-  
2 ity.

3 Fig. 4c illustrates what will happen if only the image data are shifted for  
4 the second print station 5' in order to compensate the detected lateral shift of  
5 the recording medium. In Fig. 4c, a corresponding shift of the image data rela-  
6 tive to the second print station 5' by one pixel in the upward direction is indi-  
7 cated by an overlaid shifted input image data 20 (shown in gray) and by an  
8 arrow above the field 20. The second print station's print mask 21' is effec-  
9 tively not complementary to the first print station's print mask 21, as in Fig. 4b.  
10 Again, as a result, many of the pixels of the printed image 23 are inked twice,  
11 and many others are left blank, resulting in an image of relatively poor image  
12 quality, similar to the one obtained in Fig. 4b.

13 Fig. 4d illustrates what will happen if only the print mask 21' of the sec-  
14 ond print station 5', but not the input image data 20, is shifted upwardly by  
15 one pixel in order to compensate the detected lateral shift of the print medium  
16 (the shift of the print mask 21' is indicated by arrow in Fig. 4d). A certain im-  
17 provement is now achieved, owing to the fact that the regular checkerboard-  
18 like parts of the print masks are now again complementary (relating to the  
19 occurred lateral shift of the print medium). However, as the positions of faulty  
20 nozzles are physically fixed at the respective print station (in Fig. 4, the posi-  
21 tion of the second print stations' faulty nozzle is fixed at the position of the  
22 fifth nozzle), such a shift of the print mask 21' does not cause the faulty noz-  
23 zle to be shifted in unison. Rather, the faulty nozzle stays where it is, and the  
24 shifted print mask 21' therefore no longer corresponds to the faulty-nozzle  
25 situation. As can be seen in Fig. 4d, the shifted print mask 21' has a blank  
26 row, although the corresponding nozzle of the second print station is opera-  
27 tive, but has a normal checkerboard row at the position of the faulty nozzle.  
28 As a consequence, no complete error hiding is achieved. Nevertheless, the  
29 final printed image 23 has a better image quality than the one of Figs. 4b and  
30 4c, due to the effective complementarity of the print masks 21, 21' in their  
31 regular parts.

32 Fig. 4e illustrates what will happen if not only the input image 20 is  
33 shifted (as in Fig. 4c), but also the print mask 21 of the second print station 5'

1 is shifted upwardly (as in Fig. 4d) by one pixel in order to compensate the de-  
2 tected lateral shift. Again, no complete error hiding is achieved. The printed  
3 image is similar to the one obtained in Fig. 4d. This illustrates that a complete  
4 error hiding is generally not achieved by simply countershifting the input im-  
5 age and the print mask of a print station at which a lateral shift is detected.

6 Fig. 4f illustrates the full error-hiding approach. Both the input image  
7 data 20 and the second print mask 21' are shifted upwardly by one pixel, as  
8 illustrated in Fig. 4e. In addition, the changed position of the faulty nozzle  
9 relative to the shifted recording medium is taken into account in the new print  
10 mask 21'. As can be seen in Fig. 4f, the print mask's row which is entirely set  
11 to the value "0" is now at the sixth row (rather than its fifth row), correspond-  
12 ing to the changed relative position of the faulty nozzle. Since the print mask  
13 21, 21' of the redundancy group ought to be complementary, also the first  
14 print mask 21 is replaced by a new print mask 21 the sixth row of which  
15 (rather than the fifth row) is entirely set to the logical value "1". The new print  
16 mask 21 causes the first head to print all pixels which the second print sta-  
17 tions defective nozzle cannot print; in turn, the new print mask 21' disables  
18 only the defective nozzle. As can be seen in Fig. 4f, the finally printed image  
19 23 equals the input image 20. Accordingly, by the print-mask replacing  
20 method illustrated in Fig. 4f, complete error hiding is achieved. Fig 5. shows a  
21 flow diagram of two exemplary processes relating the lateral-position-change  
22 compensation with error-hiding print masks described above. The process  
23 illustrated at the left-hand side of Fig. 5 runs from time to time between print  
24 jobs. It starts with printing a test pattern, which is observed by the nozzle-error  
25 detector 10 (Fig. 1). The sensor data is analyzed to identify faulty nozzles. If  
26 new faulty nozzles are detected, a new set of print masks is calculated which  
27 also takes into account the new faulty nozzles. The set includes correlated  
28 print masks for each print station and each possible set of lateral positions of  
29 the recording medium at the different print stations. The calculated new set of  
30 print masks is stored in the print-mask memory.

31 The process illustrated at the right-hand side of Fig. 5 runs during print  
32 processes, for example from page to page, or several times within a page. In  
33 Fig. 5, it is assumed that certain print masks are already in use for a given

1 lateral position of the recording medium. During the print process, encoding  
2 marks indicative of the recording medium's lateral position are constantly de-  
3 tected, and the recording medium's position is determined based on this. If a  
4 lateral position change is detected, the pre-calculated print masks associated  
5 with the new lateral position of the recording medium are recalled from the  
6 print-mask memory. Printing is to be continued with the new print masks in-  
7 stead of the previous ones.

8 Fig. 6 illustrates a printing device 1' having a conveyor in the form of a  
9 drum 31. A recording medium 2 is attached to the drum 31, for example by  
10 means of a vacuum system within the drum 31. Upon rotation of the drum 31,  
11 the recording medium is moved past a page-wide-array print station 5'. In or-  
12 der to keep Fig. 6 simple, only one print station 5' is shown; however, a multi-  
13 color printer will typically have a number of single-color page-wide-array print  
14 stations corresponding to the number of colors used, i.e. typically four or six  
15 print stations. The print station 5' is equipped with an array of ink-jet nozzles;  
16 it may be segmented in print heads. A page-wide nozzle-error detector 10' is  
17 attached to the print station 5 and enables faulty nozzles to be directly de-  
18 tected, e.g. using a light-barrier array, a noise detector array or a capacitance-  
19 change detector array.

20 An actuator 32, e.g. a piezo actuator, is provided which enables the print  
21 station 5' to be shifted in the lateral (i.e. axial) direction in a controlled man-  
22 ner. The actuator 32 is equipped with a print-station-displacement-  
23 measurement device which measures the print station's current lateral posi-  
24 tion. The actuator 32 is controlled by a controller 6' of the printing device 1',  
25 and the print-station-displacement-measurement device supplies its signals  
26 back to the controller 6'.

27 In the printing device 1' of Fig. 6, redundancy is achieved by rotating the  
28 recording medium more than once past the print station 5', and by laterally  
29 shifting the print station 5' between the drum revolutions. The controller 6'  
30 provides the print station 6' with a first print mask for the first revolution, and  
31 with a second, complementary print mask for the second revolution (in the  
32 case of two-fold redundancy).

33 A recording-medium sensor 11' is arranged to measure the recording

1 medium's current lateral position near the print station 5'. It is, for example, an  
2 optical surface-recording arrangement which detects and records surface im-  
3 ages of the recording medium (e.g. of the fiber structure of a paper sheet)  
4 during the drum rotation. It detects lateral displacements of the recording me-  
5 dium by comparing currently detected surface images with stored surface im-  
6 ages recorded during the previous revolution(s). In some embodiments, two  
7 such sensors are positioned at a small distance along the circumference of  
8 the drum. The second sensor detects lateral displacements of the recording  
9 medium by comparing currently detected surface images with stored surface  
10 images just recorded by the first sensor. This enables lateral displacements of  
11 the recording medium to be immediately (i.e. within the currently printed  
12 page) detected and corrected (by replacing the current print mask by a new  
13 one relating to the changed lateral position). Information obtained about lat-  
14 eral displacements of the recording medium are input into the controller 6'.

15 The controller 6' provides the print station 5' with image data to be  
16 printed and print masks controlling the print activity. The print masks are ar-  
17 ranged such that print activity distribution and error hiding is achieved, as ex-  
18 plained in connection with Fig. 4 (however, a complete error hiding will not be  
19 achieved in what has been called the "transitional region" above). If the print  
20 station's lateral position is changed by the actuator 32 and/or an unintended  
21 lateral displacement of the recording medium 2 relative to the drum 31 is ob-  
22 served, the currently used print mask is replaced by another one relating to  
23 the new lateral position of the print station 5', measured by the print-station-  
24 displacement-measurement device, and/or the recording medium 2, meas-  
25 ured by the recording-medium sensor 11'. The new print mask relates to the  
26 new relative lateral position between the print station 5' and the recording  
27 medium 2. The mechanisms of the print activity distribution, error hiding and  
28 print mask generation and replacement are analogous to what has been de-  
29 scribed above, also in connection with Fig. 4. The controller 6' is analogous to  
30 the controller 6 of Fig. 1; for example, it has a print mask calculator, a print  
31 mask memory, and a print data generator.

32 Faulty nozzles are observed by the nozzle-error detector 10', and new  
33 sets of print masks which take into account the observed faulty nozzles are

1 pre-calculated and stored in the print mask memory, as described above, also  
2 in connection with the left-hand side of Fig. 5. During the print process, after  
3 having determined an (intended or unintended) shift of the relative lateral po-  
4 sition between the print station 5' and the recording medium 2, the print mask  
5 associated with the new relative lateral position are recalled from the print  
6 mask memory and are used during the print process, as described above,  
7 also in connection with the right-hand side of Fig. 5.

8 Thus, the multi-station and multi-pass embodiments described above, in  
9 particular the devices 1, 1' of Figs. 1 and 6, are analogously arranged and  
10 controlled, and work in an analogous manner. That parts of the description of  
11 features of the multi-station embodiments which have not been expressly  
12 mentioned in connection with the multi-pass embodiments, therefore also ap-  
13 ply in an analogous manner to the multi-pass embodiments.

14 The embodiments described enable lateral-position changes of the re-  
15 cording medium to be compensated in printing devices using error-hiding print  
16 masks. The compensation may be performed in real time during the print  
17 process. Thereby, image quality is improved.

18 All publications and existing systems mentioned in this specification are  
19 herein incorporated by reference.

20 Although certain methods and products constructed in accordance with  
21 the teachings of the invention have been described herein, the scope of cov-  
22 erage of this patent is not limited thereto. On the contrary, this patent covers  
23 all embodiments of the teachings of the invention fairly falling within the scope  
24 of the appended claims either literally or under the doctrine of equivalents.